TIM 2

I. Executive Summary

II. Broadband Passive AMCs

III. Reconfigurable AMCs

IV. Computational Tools Development

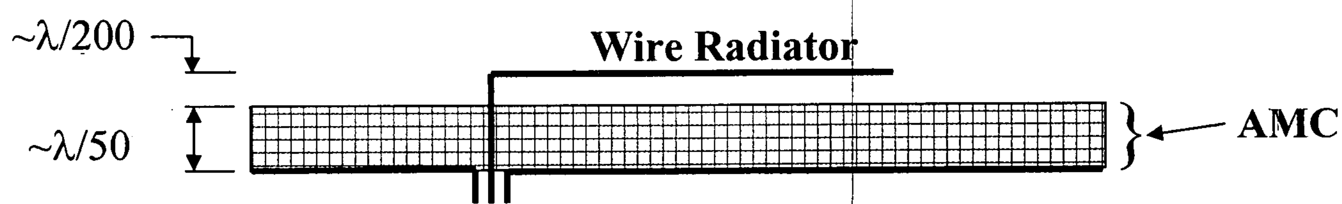
V. Schedule and Financial

VI. RECAP System Demonstration(s)

ARCHES Basic Technical Approach

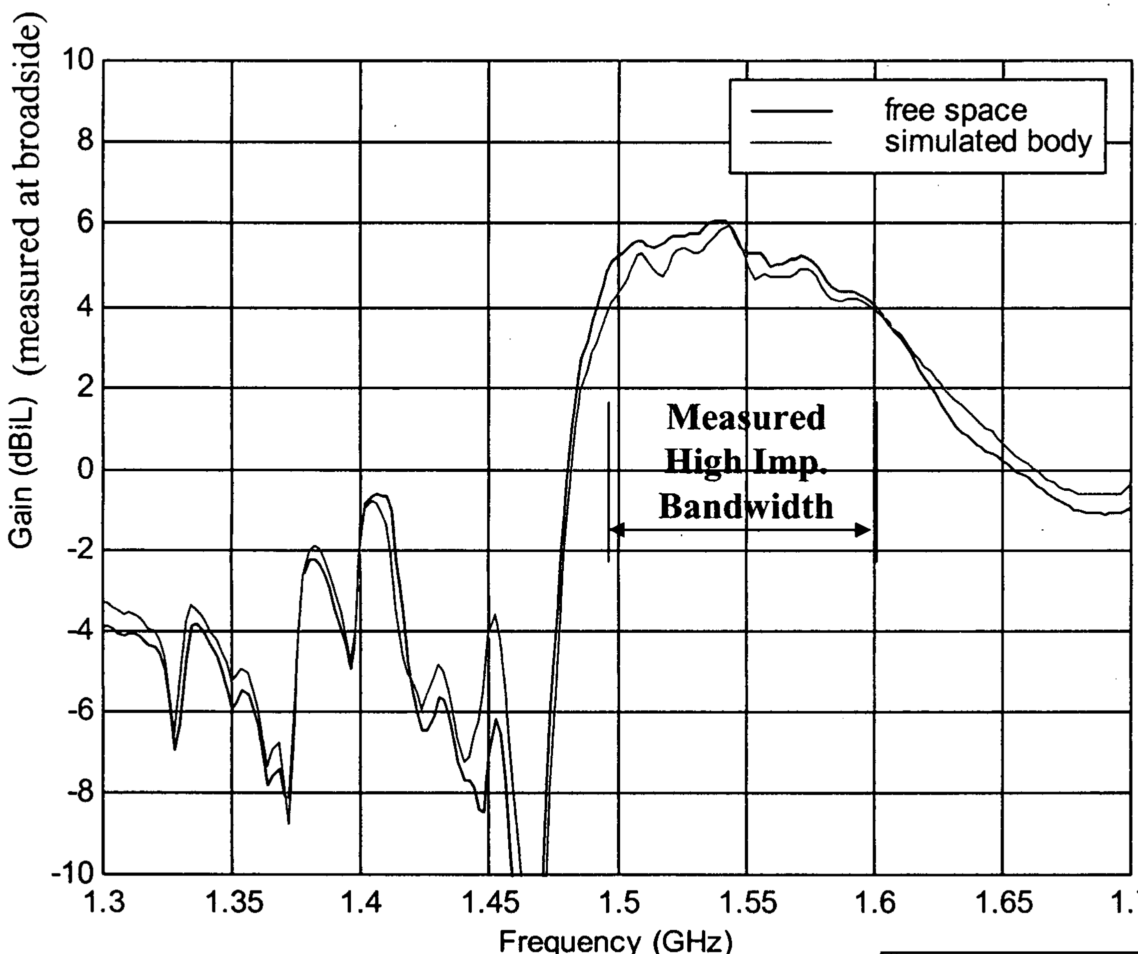
1. Create an electrically-thin Artificial Magnetic Conductor (AMC).
   a. High-impedance surface, $Z_s = E_{tan}/H_{tan}$, were $H_{tan} \sim 0$.
   b. Surface wave bandgap exists were $|Z_s| > \eta_o$.

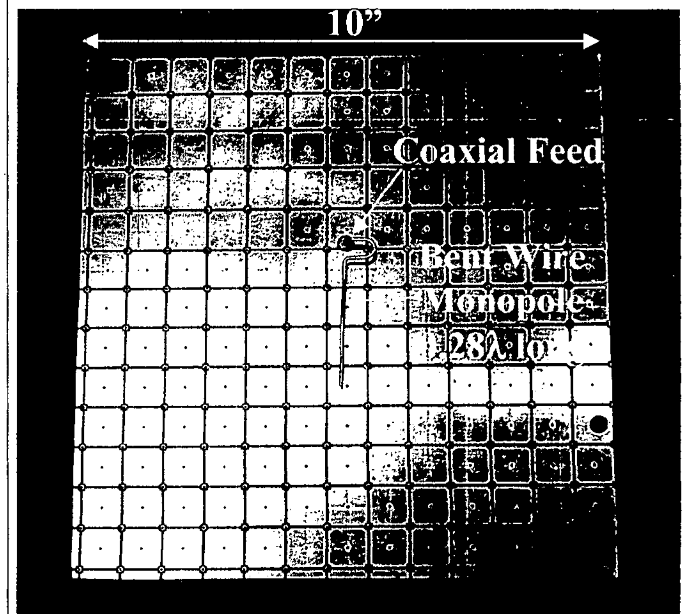
2. Fabricate wire antenna elements in close proximity to the AMC.
   a. High gain, 4 to 6 dBil per element, occurs across the surface wave bandgap frequencies.



3. Electronically reconfigure both the element resonant frequency and the AMC resonant frequency for multi-band operation.

Example of an AMC Antenna: Bent-Wire Monopole





Human torso simulated with a 5 gallon plastic bucket of tap water.

High gain (~4 to 6 dBil) is available over the entire high impedance bandwidth (bandgap)!

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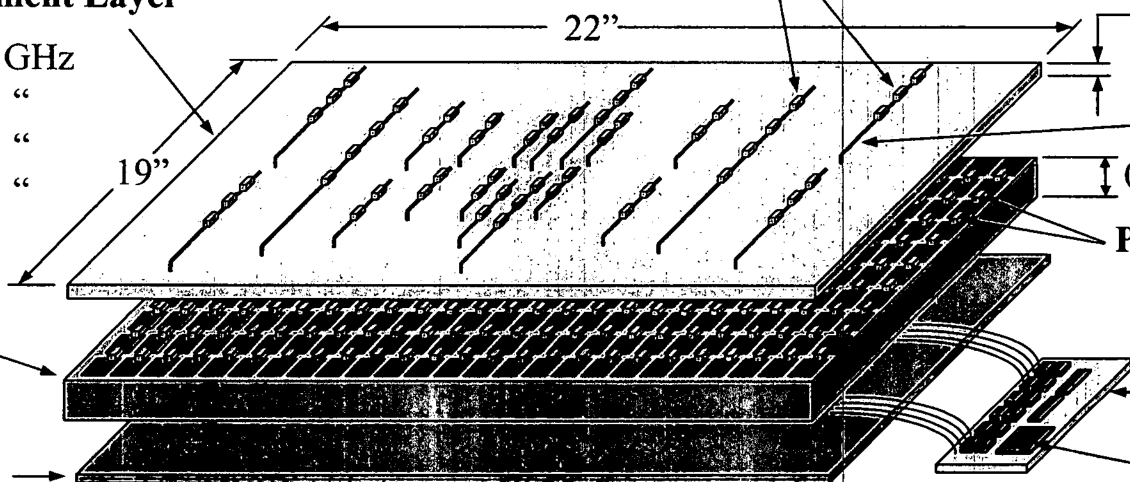
Proposed ARCHES 0.2-2.0 GHz Demonstration Array

Features:
- Very thin structure, ~ 1 inch thick (thinner for frequencies above 2 GHz)
- Aperture area scales with frequency band - relatively constant beamwidth
- Rapid electronic switching - 10's of μsec



Potential Applications:

- UHF SATCOM
- UHF LOS Comm.
- JTIDS
- FOPEN
- VHF LOS Comm.
- ULTRA-COMM
- SUO
- JTRS
- ESM
- SIGINT
- L-Band Data Links
- IFF

ARCHES Program Goals

Task	Parameter	Goal
Passive AMC	Bandgap Bandwidth	Octave
	Thickness	$< \lambda_{max} / 50$
Reconfigurable AMC	Operational Bandgap	.2 - 2 GHz
	Thickness	< .75 inch
Reconfigurable Element	Instantaneous BW	15%
	Operational BW	Octave
	Element Gain	> 4 dBil
Array Demonstration	Operational Frequency	0.2 - 2 GHz
	Instantaneous BW	15%
	Array Size	19" x 22"
	Number of Elements	2 or 6
	Array Gain	12 dBil for the 6 element mode
		7 dBil for the 2 element mode
	Array Thickness	1 inch max.
	Fixed Beam	
	Computer Controlled	
Modeling and Simulation		1. New effective media models for AMCs
		2. Spectral domain analysis code for arrays of elements integrated into AMCs

ARCHES Task Description

Antennas in ReConfigurable High-impedance Electromagnetic Surfaces

1.0 Integrated Ground Plane (IGP) Technology Dev: Conduct research and technology development needed to realize broadband and/or reconfigurable artificial magnetic conductors (AMCs) with embedded radiating elements.

1.1 Passive Broadband AMC Dev.: Design, model, fabricate, and test hardware concepts for increasing the bandgap of AMCs. Both circuit and material approaches will be used. The goal is a 2:1 bandgap in the 0.2-2.0 GHz band.

1.2 Reconfigurable Bandgap AMC Dev.: The basic goal is to realize a frequency tunable AMC, where the bandgap may be electronically reconfigured by controlling the reactive nature of the high-impedance surface using arrays of solid state devices. The goal is to reconfigure the bandgap to cover 0.2-2.0 GHz.

1.3 Reconfigurable Radiating Element Dev.: Electronically switched radiators compatible with high-impedance surfaces will be modeled, built, and tested. The goal is to produce reconfigurable elements with a 10:1 operational bandwidth in the 0.2 to 2.0 GHz band.

1.4 Electronic Controller Dev.: Software and hardware will be created to control reconfigurable elements and AMCs.

2.0 Computational Tool Dev.: Create electromagnetic modeling, simulation, and design tools for AMC structures based on effective media models and MoM spectral domain algorithms. This task will be led by Rudy Diaz at ASU.

3.0 Antenna Array Demonstration: This task will integrate reconfigurable elements, a reconfigurable AMC, and the electronic controller technology to create a 10:1 operational bandwidth array covering 0.2 - 2.0 GHz.

4.0 Program Management: TIM's, status reports, and technical reports.

What's New and Original with the ARCHES Program?

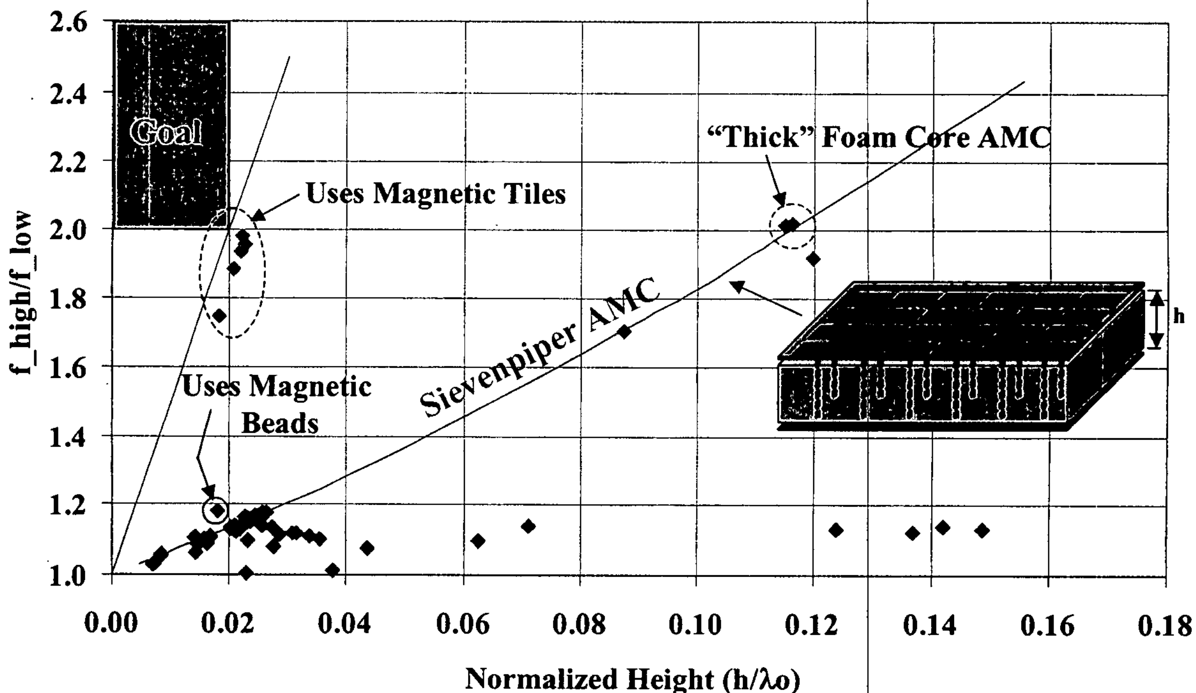
First 6 month's effort:

- **Techniques to increase the bandwidth of the Sievenpiper AMC concept**
- **Alternative AMC structures which differ from Sievenpiper's approach**
- **Techniques to electronically control or reconfigure the AMC bandgap(s)**
- **New ideas for low cost printed antenna elements that can be integrated into AMC designs**
- **Concepts for effective media electromagnetic modeling of AMCs which may facilitate rapid design and analysis of AMC integrated antennas**

Progress on Broadband Passive AMCs

What has not worked: modifications using
- a) lumped inductors,
- b) septums
- c) TEM trans. lines, ...

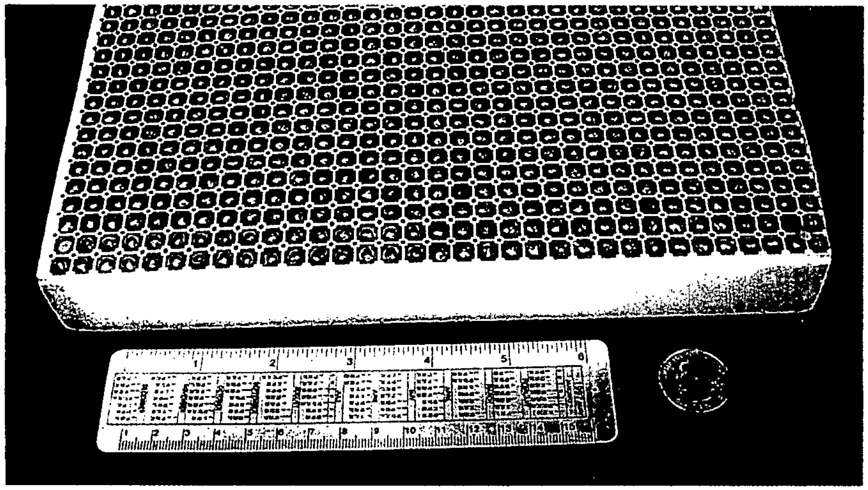
What has worked: modifications using
- a) artificial magnetic materials
- b) magnetic beads



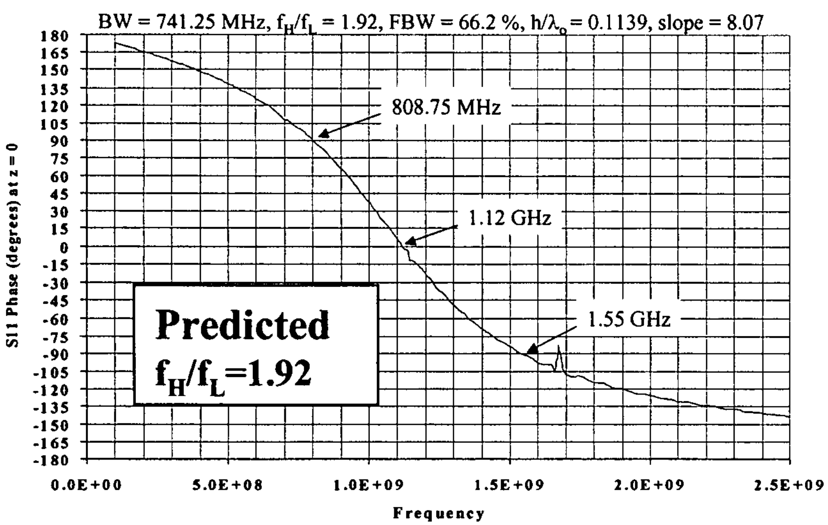
The use of Barium Cobalt hexaferrite tiles in a 400-800 MHz AMC design obtains a bandwidth performance very close to the goal.

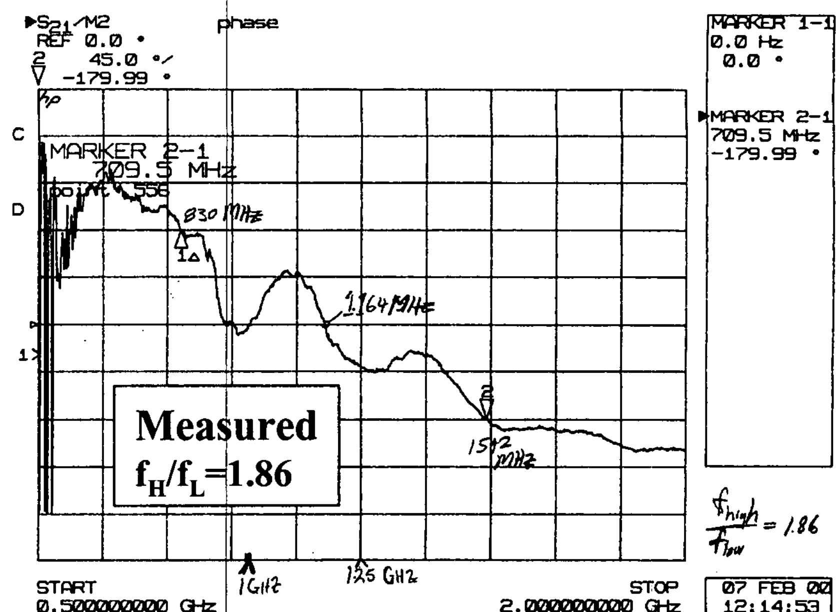
Non-Magnetic, Octave Bandwidth AMC

AMC_12-4, 800 MHz to 1600 MHz Goal



Bandwidth: 830 MHz to 1540 MHz.
Area: 10 in. x 16 in. (.103 m^2)
Thickness: 1.26 in.
Weight: 3 lb, 2 oz (1.42 kg) or 13.76 kg/m^2

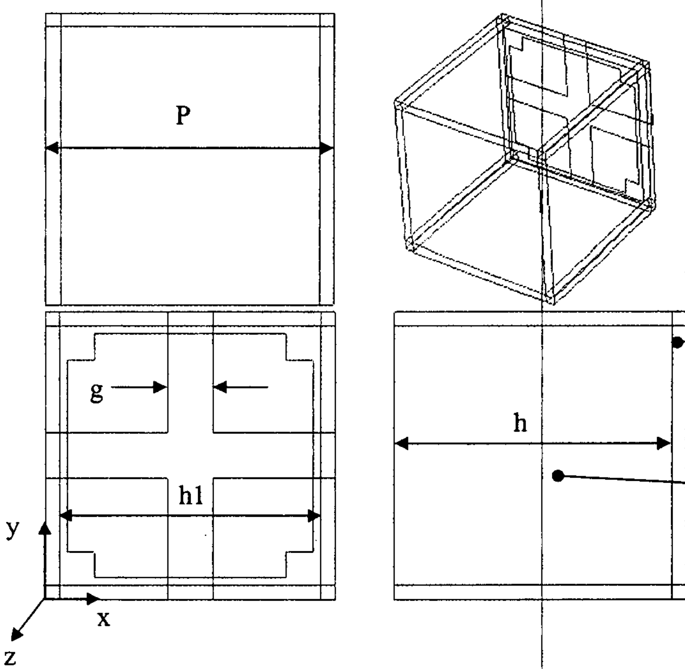




Magnetic, Octave Bandwidth AMC Design

AMC 34, 400 MHz to 800 MHz Goal

- **400 MHz to 800 MHz**
- **0.475 inches thick**
  (λ/40 at 600 MHz)
- **Unaligned Barium Cobalt**
  hexaferrite tiles
- **Weight = 9.8 lb/ft²**

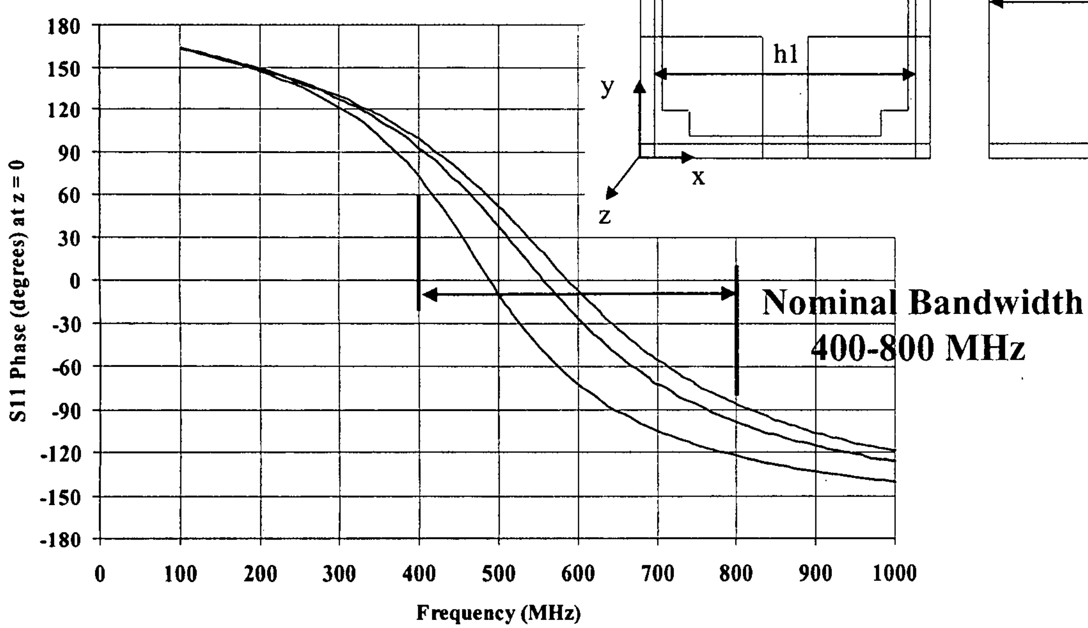


Square unit cell
P = 11.1252 mm (438 mils)
g = 1.6948 mm (66.724 mils) AMC_34
= 2.4444 mm (96.236 mils) AMC_34-2
= 2.7126 mm (106.795 mils) AMC_34-3
h = 10.668 mm (420 mils)
h1 = 10.0076 mm (394 mils)
t = 0.508 mm (20 mils)
via = 1.1176 mm (44 mils)

Material of dielectric constant 3.38

Hexaferrite material with $\varepsilon_r = 9$, $\mu_r = 11$ and $\sigma_m = 10.4223K$

Via: One each located at the corners

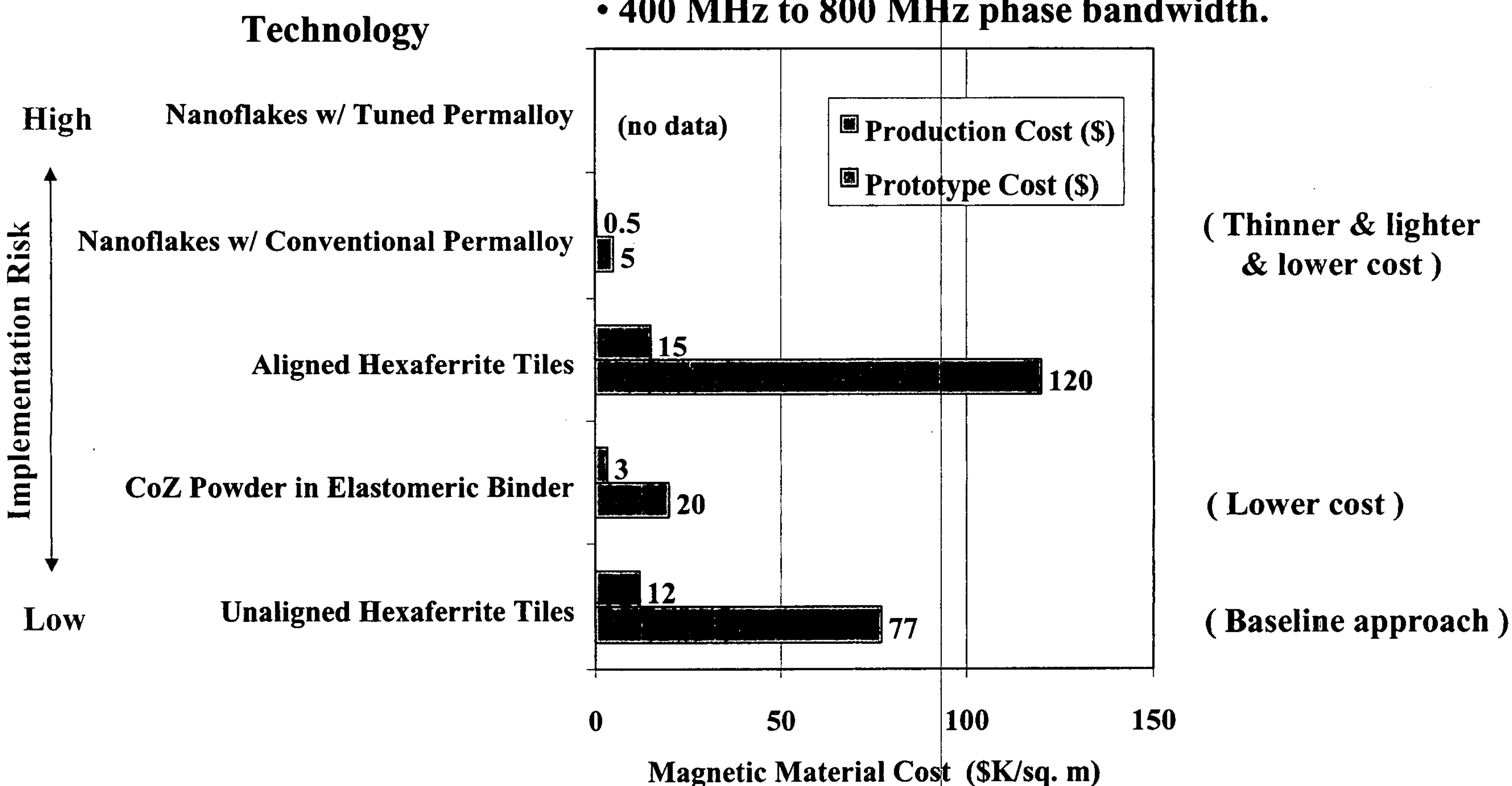


Incident Wave TEM Polarization: Ex

Filename	AMC_34	AMC_34-2	AMC_34-3
Capacitance/sq.	0.82 pF	0.512 pF	0.418 pF
+90°	371..308 MHz	406.022 MHz	421.622 MHz
0°	490.982 MHz	556.897 MHz	586.342 MHz
-90°	647.057 MHz	763.286 MHz	815.289 MHz
BW	275.75 MHz	357.26 MHz	393.67 MHz
f_H/f_L	1.74	1.88	1.93
FBW	56.20%	64.15%	67.14%
h/λ_o	0.0183	0.0207	0.0218
slope	40.44	42.51	42.84

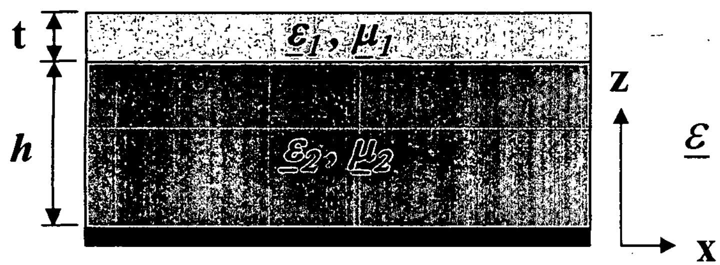
Estimated Cost of Artificial Magnetic Materials for an Octave Bandwidth AMC

• 400 MHz to 800 MHz phase bandwidth.



Notes: 1. The AMC has a 400 MHz to 800 MHz phase bandwidth.
2. The cost of the printed FSS and backplane are estimated to be an additional \$2,000/(sq. m) in production.
3. See Rodger Walser for a cost estimate of Nanoflakes with a Tuned Permalloy.

Effective Media Model of the Sievenpiper AMC



$$\underline{\varepsilon} = \varepsilon_o \begin{pmatrix} \varepsilon_{xx} & 0 & 0 \\ 0 & \varepsilon_{yy} & 0 \\ 0 & 0 & \varepsilon_{zz} \end{pmatrix} \quad \underline{\mu} = \mu_o \begin{pmatrix} \mu_{xx} & 0 & 0 \\ 0 & \mu_{yy} & 0 \\ 0 & 0 & \mu_{zz} \end{pmatrix}$$

Upper Layer*:

$$\varepsilon_{1xx} = \varepsilon_{1yy} = \frac{2b}{\pi t_1} \ln\left(\frac{2b}{\pi g}\right) \varepsilon_{avg}$$

$$\varepsilon_{1zz} = 1$$

$$\mu_{1xx} = \mu_{1yy} = 1$$

$$\mu_{1zz} = \frac{\varepsilon_{avg}}{\varepsilon_{1yy}}$$

where $\varepsilon_{avg} = \dfrac{1+\varepsilon_D}{2}$

*Assumes a single layer FSS with edge coupling

Lower Layer:

$$\varepsilon_{2xx} = \varepsilon_{2yy} = \varepsilon_D \left(\frac{1+\alpha}{1-\alpha}\right) \qquad \mu_{2xx} = \mu_{2yy} = \frac{\varepsilon_D}{\varepsilon_{2xx}} \mu_D$$

$$\varepsilon_{2zz} = \varepsilon_D - \frac{1}{\omega^2 \varepsilon_0 \dfrac{\mu_D \mu_o A}{4\pi} \left[\ln\left(\dfrac{1}{\alpha}\right) + \alpha - 1\right]} \qquad \mu_{2zz} = (1-\alpha)\mu_D$$

where $\alpha = \dfrac{\text{Cross sectional area of each via}}{\text{Area of the unit cell for the rodded media}}$

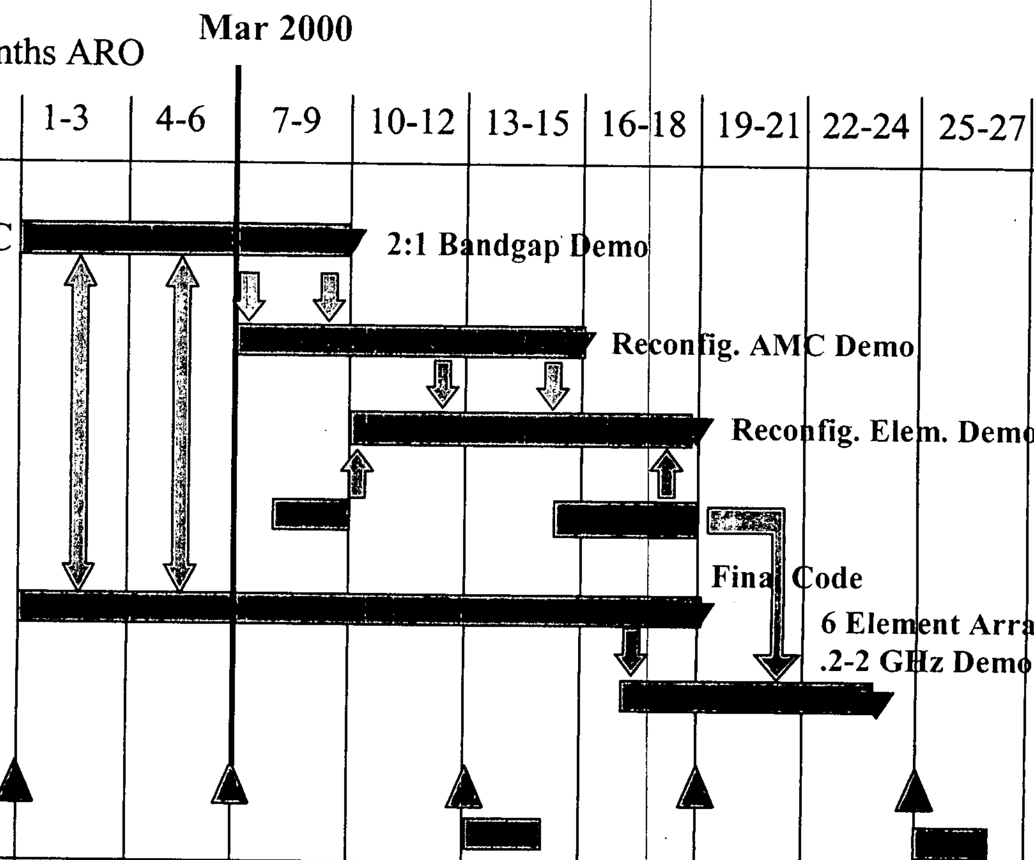
ε_D = Relative permittivity of the background dielectric

μ_D = Relative permeability of the background dielectric

ARCHES Technical Status

- Completed 6 months of a 9 month passive AMC design effort. On schedule to create the 2:1 bandwidth AMC demo:
  - Demonstrated a nonmagnetic, octave BW AMC with $h/\lambda_0 = .11$ (too thick)
  - Magnetic tile, octave bandwidth AMC design is completed and now in fabrication with $h/\lambda_0 = .02$
  - Two additional artificial magnetic materials are being fabricated for AMCs:
    - Barium Cobalt hexaferrite powder in an elastomeric binder
    - Permalloy nanoflakes in an elastomeric binder
  - Completed a preliminary cost/weight/thickness study of artificial magnetic materials for AMCs
- Completed a 2 layer effective media model for the Sievenpiper AMC.
- Completed development of a transverse resonance model which predicts TE and TM mode cutoff frequencies for the Sievenpiper AMC. (APS 2000 paper)

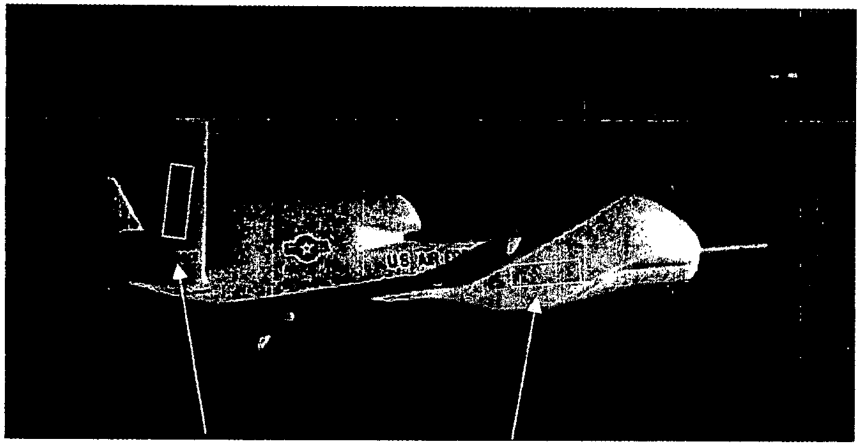
ARCHES Schedule, Milestones, and Cost



Task	Cost ($K)	Spent ($K)
1.1 Passive Broadband AMC	331	235
1.2 Reconf. Bandgap AMC	552	0
1.3 Reconf. Elements	407	0
1.4 Electronic Controls	115	0
2. Computational Models	610	47
3. Array Demo	292	0
4. Meetings & Tech Reports	234	66

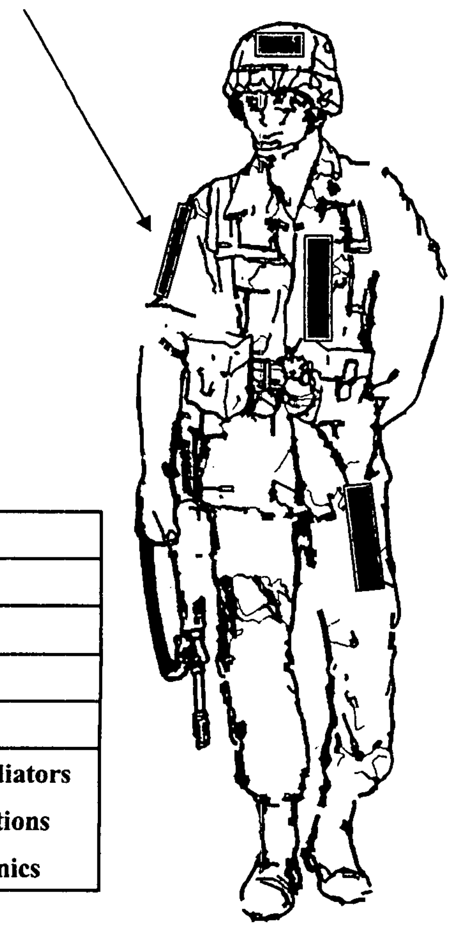
	1-3	4-6	7-9	10-12	13-15	16-18	19-21	22-24	25-27	
Cost/Qtr ($K)	305	166	321	535	483	371	145	177	36	
Cost/Year ($K)	Yr 1 = 1,327				Yr 2 = 1,176				Yr 3 =36	348 total

Potential ARCHES Program Payoff



Concepts for “paste-on” airborne communication and/or radar arrays.

Thin, conformal, reconfigurable antennas for the dismounted-warfighter



Features	Benefits
1. Electrically-thin aperture	1. "Paste-on" applications
2. Electronically reconfigurable in frequency	2. Multi-function applications
3. Lightweight	3. Mobile and/or man-portable applications
4. Printed antenna construction	4. Potential for low-cost fabrication
5. Radiation is restricted to one hemisphere due to the conducting backplane.	5a) Potential 3 dB gain improvement over bidirectional radiators 5b) Mitigation of body absorption for man-portable applications 5c) Mitigation of EMI/EMC effects with integrated electronics